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Information Technology Based Active Learning: A Pilot Study for Engineering Economy

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Information Technology Based Active Learning: A Pilot Study for Engineering Economy

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Abstract

We have recently designed a learning environment to add practical problem solving, increased information technology content, and active learning to industrial engineering courses. In particular, we have successfully implemented and tested a computer-based module for an undergraduate engineering economy course. In this module, students are required to formulate the problem, devise a plan of action, and derive a final solution using the domain knowledge acquired in class. In addition to improving understanding of the course material, the module is also designed to improve more general cognitive skills and specifically to enhance the metacognitive ability of the participating students. A prototype of the module is currently being used in a classroom setting and we report on our initial experiences and student outcomes. We also discuss how this will be extended to an active learning environment that uses information technology across the curriculum to integrate all required undergraduate courses.

1. Introduction

Using information technology (IT) to improve engineering education offers much promise for educational improvements[7,16,20], but also requires careful consideration of both technical content and of learning objectives. In this paper we describe our recent and ongoing work in designing and developing an IT-based learning environment that both effectively delivers the desired technical content and promotes learning that we value by improving students' cognitive skills.

The first implemented phase of the new learning environment is a module developed for engineering economy and a pilot study has been conducted using this module in a classroom setting. This module and our initial experience are described in some detail below. Based on the results obtained, we also describe how we plan for this environment to be expanded and eventually integrate the entire undergraduate curriculum via a network of interconnected modules.

The ultimate success of IT in the classroom hinges to great extent on its ability to address challenges that may be difficult to solve without the enabling technology. One clear potential for using information technology to improve upon traditional lecture classes is to use it to promote collaborative learning[19] and active learning[12,13]. Specifically, using information technology, sophisticated simulated environments can be created that allow students to address realistic problem scenarios in a hands-on fashion using domain knowledge mastered in the relevant courses[4].

There are also many other challenges in education where information technology can be used as an enabler. For example, the traditional industrial engineering curriculum includes what may seem like loosely connected courses that address different elements of manufacturing and service enterprises. A common IT-based environment can be used to integrate these courses. As another example, such an environment can also be used to encourage the development of specific learning skills. In traditional educational environments it is difficult to monitor and encourage students' metacognitive activities, such as planning how to learn a given task, monitoring comprehension of the task, and evaluate the progress towards completing the task. On the other hand, such metacognition has been found to be important to learning and we believe an IT-based environment can enable monitoring and development of those skills.

Thus, we have identified several elements that we believe are important in an information technology based learning environment and we have incorporated these elements into the development of the engineering economy module and the design of the broader learning environment. In particular, the learning environment should:

- Make connections between the course material and real-world problems by presenting realistic problem scenarios.
- Emphasize relationships between previously isolated parts of the curriculum.
- Help develop both students' cognitive ability to structure schemas in industrial engineering knowledge domains and their metacognition.
- Increase active learning and collaborative learning.

The remainder of the paper describes how these objectives are addressed in the engineering economy module and the broader design for a learning environment, and is organized as follows. In Section 2 we discuss the engineering economy module that serves as the initial prototype for the learning environment, and in Section 3 we describe how metacognitive skill development is incorporated into this module. In Section 4 we present the results from a pilot study conducted using the module in a classroom setting. In Section 5 we discuss our designs of a broader framework for a learning environment encompassing the entire undergraduate curriculum, and finally in Section 6 we make some concluding remarks and discuss ongoing and future work.

2. A Module for Engineering Economy

As part of a new learning environment for the industrial engineering undergraduate curriculum, a first module was developed and tested in our Engineering Economic Analysis course during the Fall 2002 semester. This is a 3-credit course required for industrial engineering (IE) juniors. It is also a requirement for electrical engineering majors and a popular elective for majors in mechanical and chemical engineering. Most of the non-IE majors take the course as seniors.

2.1 Scenario Description

The engineering economy scenario was developed in consultation with a local manufacturer of professional concession equipment. This company faced a production bottleneck caused by the limited capacity of its punch press operation. Alternatives for expanding production capacity

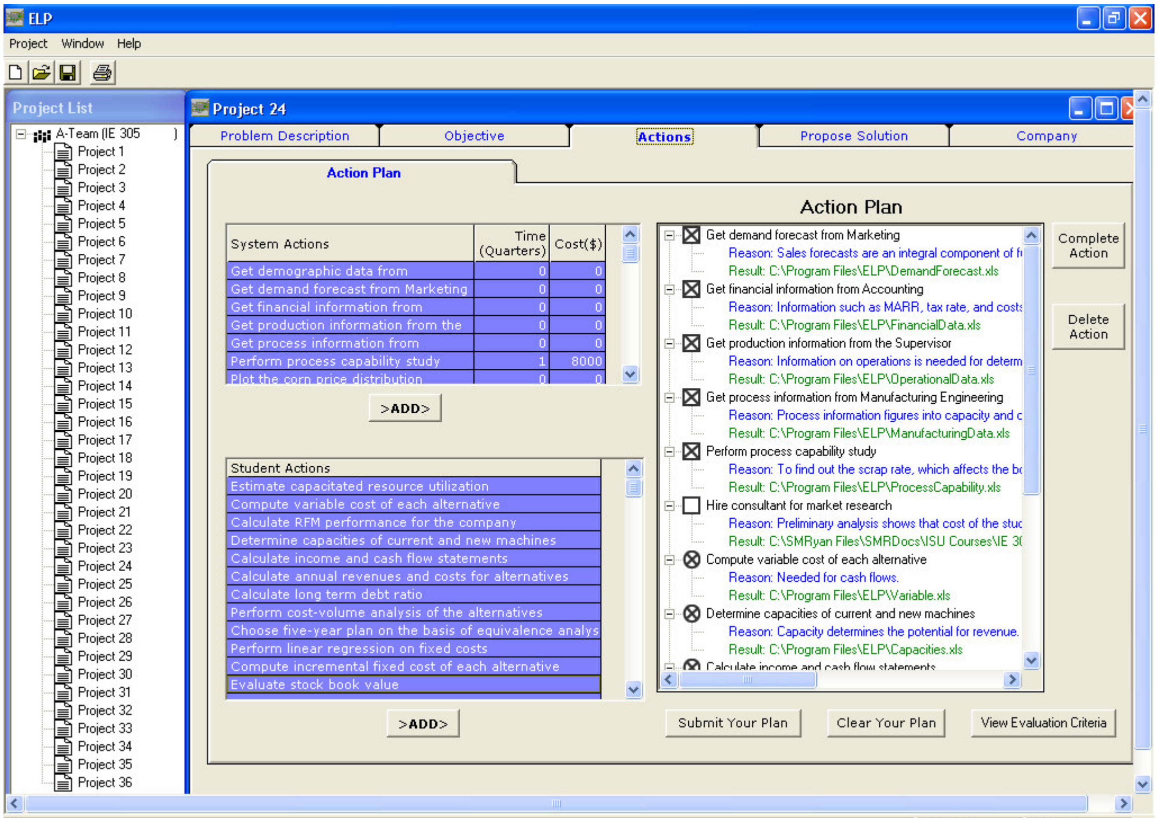

Figure 1: Screen shot of the action plan window

included purchasing a new punch press, adding a second shift using the existing press, and partially outsourcing the punching operation. The problem was to develop a manufacturing strategy for the next five years based on a set of alternatives (the outsourcing option was available only in the first two years).

The written problem description included a general description of the situation, the sequence of metal forming operations, the capacity expansion alternatives, and a range of possible demand projections over the five-year horizon. Using the system, students create a project in which they specify an objective, devise a problem-solving plan, and submit a manufacturing strategy (see tabs across the top of the screen shot in Figure 1 for the different steps). During the course of the project, justification of each element must be provided and students perform a self-evaluation that encourages them to reflect on their work.

In formulating a problem-solving action plan (window shown in Figure 1), students select from possible student and system actions listed in Tables 1 and 2, respectively, and shown to the left of the main window in Figure 1 (some possible actions are intentionally spurious). Choosing the market research option in the first year precluded any expansion alternative during the first year. However, the problem description suggested that hiring the marketing firm would both tighten the demand forecast and increase demand somewhat.

Student actions typically require some application of methods or models to achieve a specific result. System actions are typically information sets that the system can provide to the student team. These actions can incur costs as well as cause a delay in the solution timeline.

Table 1. System actions available

Action Description	Time Required (quarters)	Cost
Get demographic data from Marketing	0	0
Get demand forecast from Marketing	0	0
Get financial information from Accounting	0	0
Get production information from the Supervisor	0	0
Get process information from Manufacturing	0	0
Perform process capability study	1	$8,000
Plot the corn price distribution	0	0
Hire consultant for market research	4	$150,000

Table 2. Student actions available

Action Description
Estimate capacitated resource utilization
Compute variable cost of each alternative
Calculate RFM performance for the company
Determine capacities of current and new machines
Calculate income and cash flow statements
Calculate annual revenues and costs for alternatives
Calculate long term debt ratio
Perform cost-volume analysis of the alternatives
Choose five-year plan on the basis of equivalence analysis
Perform linear regression on fixed costs
Compute incremental fixed cost of each alternative
Evaluate stock book value

Once the team determines the manufacturing strategy (window shown in Figure 2), a spreadsheet is submitted electronically with a net income and cash flow statement for the five-year horizon (formatted as in the course text book). Students can then view the results of a quarter-by-quarter simulation of the first year, including realizations of variables such as demand, production volume, costs and net income. After the first year simulation, they may view the results of the market research study if they have chosen it, modify the alternatives chosen for years 2 through 5, and then return to run the simulation over the remaining years. After the simulation is completed, a final submission of their project is made. During this process, students can revisit their plan and make any necessary changes based on their reflections on how they approached the problem.

2.2 Administration in a Large Lecture Course

The Fall 2002 final enrollment for the course was 181 students as shown in Table 3. Because the system was a prototype version and the feasibility of evaluating a large number of projects was doubtful, we offered the module as an extra credit project and asked students to sign up in self-selected teams of 2 or 3. There were 63 projects submitted involving 151 students. Access to the

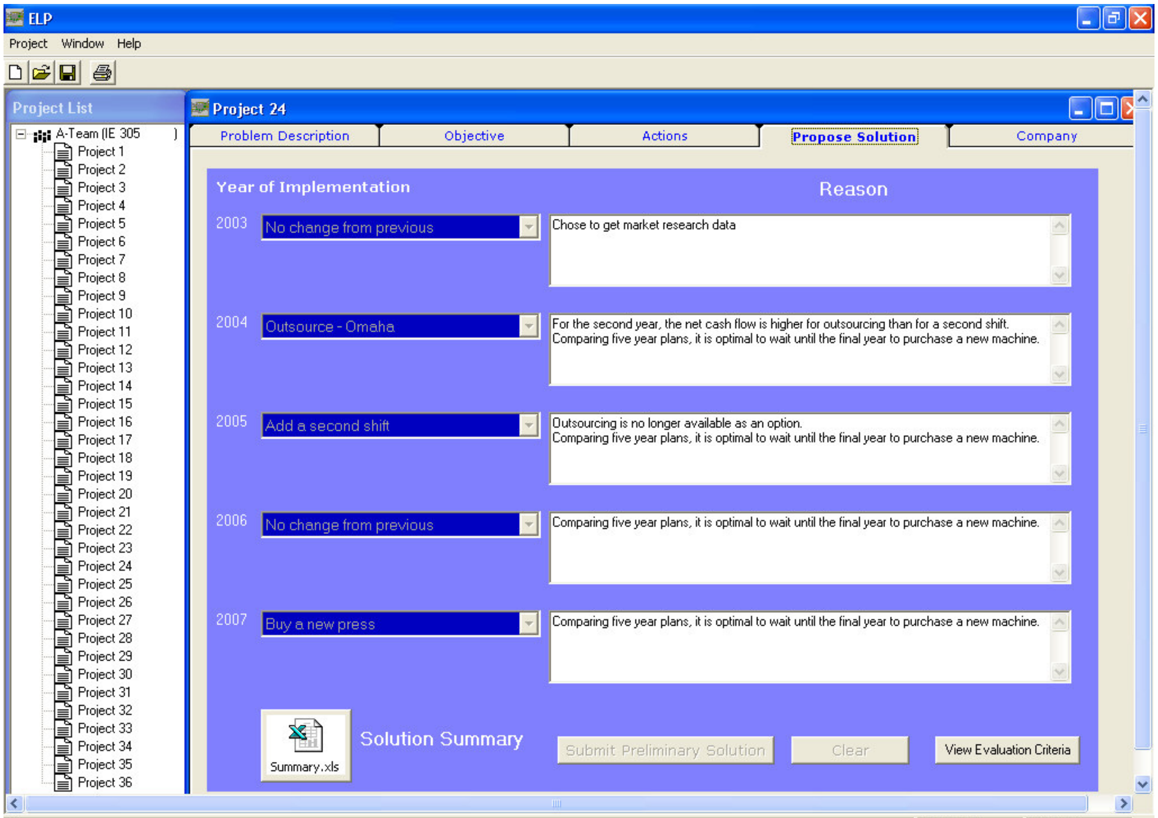

Figure 2: Screen shot of the manufacturing plan (solution) window

system was made available in a large computer lab and by download for installing on the students' own computers. We allowed two weeks for completing the project. This time window began approximately two-thirds of the way through the semester, after most of the relevant material concerning financial and cost information, money and investing, evaluating business and engineering assets and development of project cash flows, had been covered in class. Material on project risk and uncertainty was discussed in class concurrently with the case study project.

Table 3. Distribution of majors and class levels

Major\Level	Sophomore	Junior	Senior	Exchange	Graduate	Total
Industrial	6	17	8	0	0	31
Chemical	0	8	20	0	0	28
Computer	0	4	18	0	0	22
Electrical	1	14	32	0	0	47
Mechanical	0	4	30	0	0	34
Other	0	1	10	5	3	19
Total	7	48	118	5	3	181

2.3 Student Evaluation

Learner centered assessment is an important element of effective learning[11], and plays a key part in our new environment. As students progressed through the project, they had to evaluate themselves according to a set of rubrics. Table 4 shows the criteria for each rubric and a description of an exemplary project, which would receive a score of 6. The rubrics also included a description according to each criterion of a satisfactory project (4-5 points) and an unacceptable project (0-1 points), which are omitted here to save space. After the projects were submitted, the course instructor and teaching assistants evaluated them according to the same rubrics. Despite the high level of detail in the rubrics, which we feared might provide too much specific guidance; the instructor scores on the rubrics were relatively low.

Table 4. Criteria and descriptions of an exemplary project on each rubric

Objective Rubric	
Completeness	The necessary measures are included. Measures support the achievement of the goal.
Clarity	Measures and reasons are clearly defined and easily understood.
Justification	Reasons for each measure are provided and contain full justification.
Plan Rubric	
Financial	Financial information used correctly to determine incremental fixed and variable costs for each alternative.
Operational	Operational information used correctly to help determine machine capacity.
Manufacturing	Manufacturing information used to help determine costs and capacities of alternatives.
Process capability	Scrap rate based on process capability is used correctly in the analysis.
Range of plans	Full range of possible 5-year plans is considered.
Consider relevant information	Analysis includes consideration of fixed and variable costs, scrap, depreciation, taxes, time value of money.
Demand projections	The impact of different demand scenarios is considered.
Market research option	Costs and benefits of market research are weighed carefully before submitting initial five-year plan.
Solution Rubric	
Net Income	Correctly accounts for scrap rates/machine capacities, terms of the outsourcing contract, incremental fixed and variable costs, depreciation and taxes.
Cash Flows	Conversion of net income to cash flows correctly accounts for investment expense, salvage value and depreciation expense.
Time Value of Money	Computation of net present worth, annual equivalent worth, or internal rate of return is correct.

In addition, we identified the five year plan that would achieve the highest net present worth (NPW) according to the most likely demand forecast after the marketing study and assigned each team a score based on closeness of their five-year plan's NPW to this "optimal" NPW. Only two student teams chose the best plan, but 10 more groups found a plan with NPW within 1% of optimal. The worst performing plans chosen had NPWs that were 9% lower than the optimal. Over 75% of the teams specified plans with NPW errors of at least 8%.

2.4 Student Performance

Using the rubrics shown in Table 4, the average grade for the groups was 5.5 out of 10, with a minimum of 2 and a maximum of 8. The rubrics were weighted together as follows:

20% Objective rubric --- average grade of 64.6%
40% Plan rubric -- average grade of 50.9%
20% Solution rubric -- average grade of 70.9%
20% Quality of solution

As the initial pilot test was given as an optional extra credit project, these results must be evaluated with the caveat that some student may have elected to put less effort into this project than if it had been a required part of the course. Indeed, the performance of students for this project was clearly linked with the amount of effort devoted to the project. The majority of the work consisted of completing and analyzing the various actions included in the action plan (see Figure 1). Some of those actions are relevant to the problem whereas others are irrelevant. Some of the actions involve the system returning information to the students without further work on the behalf of the student (see Table 1), whereas other require the students to perform considerable calculations and analysis on their own (see Table 2).

On the average, the students chose 9.2 actions, although there was considerable variation with the standard deviation being 2.6 and one group selecting as many as 15 actions. Finding the best solution to the problem did not require doing all the actions. The two teams that identified the optimal solution included 8 and 9 actions on the action plan as is shown in Table 5, which is close to the average number of tasks, and interestingly these two teams selected an almost identical action plan.

Table 5. Actions plans for teams with best solutions

Actions Performed	Team A	Team B
Calculate annual revenues and costs for alternatives	x	x
Get financial information from Accounting	x	x
Calculate income and cash flow statements	x	x
Get production information from the Supervisor	x	x
Get demand forecast from Marketing	x	x
Get process information from Manufacturing Engineering	x	x
Compute incremental fixed cost of each alternative	x	
Hire consultant for market research	x	x
Compute variable cost of each alternative	x	x

There was, however, a correlation between the number of actions included on the action plan and the grade obtained by the group. The correlation coefficient between the grade and the number of actions selected was $\rho_{gt} = 0.49$. This suggests the somewhat obvious observation that the amount of work is reflected in the grade, and the evidence becomes stronger when we separate the number of student actions involving calculation, where the correlation coefficient is

$\rho_{gs} = 0.51$, from the number of non-calculation system actions, where the correlation coefficient is $\rho_{gn} = 0.31$. Another way of looking at this is to consider all the groups that included at least 7 actions on the action plan that involved calculation versus those that included fewer than 4 such actions. The first of those groups scored an average grade of 60/80 for the grading of the rubrics, whereas the latter had an average grade of 39/80, a significant difference. We conclude that there is a strong correlation between the amount of work students elected to include in the action plan and the final grade and it is to be expected that some groups elected to not include actions that they may have included if this was a significant portion of the course grade rather than an extra credit project. This issue will be further explored as data becomes available from the current classroom use of this module (Spring 2003), where the project accounts for 20% of the final grade.

3. Metacognition

Educational psychology has recently had significant focus on metacognition as a key enabler to being a successful learner[1,2,5,8,9,10,18]. Sometimes referred to simply as "thinking about thinking," metacognition differs from just cognition it that it refers to higher order thinking that involves active control over the cognitive processes engaged in learning. This may involve numerous activities, such as planning how to learn a given task, monitoring one's comprehension of the task, and evaluating the progress that is made towards the task.

Several researchers have recently focused on the application of metacognitive theory in education[3,6,14,17,21]. It has been observed that as students become aware of their own thinking and problem solving process their learning can be enhanced. One of the key innovative elements of the new learning environment is a focus on the development of metacognitive skills. Thus, the several elements are incorporated into the modules that explicitly encourage students to reflect critically on their work, monitor their progress towards understanding the problem, planning the problem solving process, and evaluating their progress.

As mentioned above, before moving on to the next phase of the projects, students are required to provide a self-evaluation based on the same rubric that is used by the instructors. For example, as indicated by Table 4, before leaving the objective phase the students are prompted to evaluate the completeness, clarity, and justification of the objective (see Figure 3). Thus the IT is used to encourage student reflection and possibly revision based on this reflection. The standard for measuring the evaluation factors is made available to the students and they can be previewed at any time while the students are solving the problem. As shown in Table 4, completeness should be rated as exemplary if the necessary measures are given and these measures support the achievement of the goal. It is satisfactory if there are a few missing or inappropriate measures, and unacceptable if inappropriate measures are specified and measures are not consistent with the goal. The purpose of the self-evaluation is to encourage students to reflect on their work and make revisions as necessary if it does not meet the set criteria.

In addition to the self-evaluations, students are required to explain and justify their actions throughout the module. For example, students must explain why they select their objective and why a specific task is included on the action plan. This is again intended to encourage students to be reflective and understand their own thought and problem solving processes.

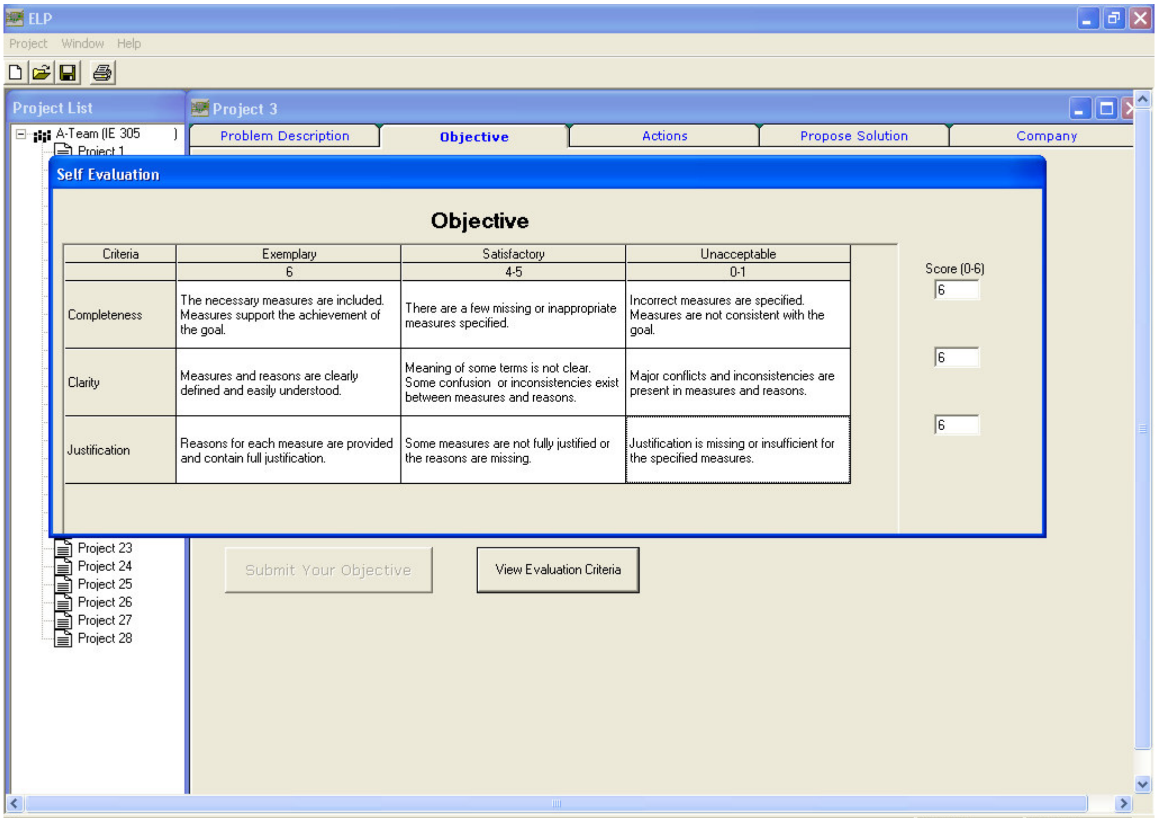

Figure 3: A screenshot of the self-evaluation rubric

Our experience from the pilot study indicates that students are not accustomed to these types of reflections and in many cases gave either non-specific explanations or tried to go beyond what would be required for an explanation. We take this as an indication for the need to incorporate metacognitive skill development into the entire curriculum and expect as students move through such modules in a series of courses they will enhance their ability to reflect on their actions.

Not surprisingly, students' self-evaluations tended to be higher than the instructor evaluations. However, intuitively we believe that students with better metacognition will be more accurate in their self-evaluations. We are therefore interested in seeing if those groups that had more accurate self-evaluations did better on the project in terms of the final grade assigned. To that end, we calculate for each of the 63 groups, the average squared deviation between the self-evaluated and instructor-evaluated rubric:

$$\psi_g = \frac{1}{3}\sum_{i=1}^{3}\left(x_{ig} - y_{ig}\right)^2, \; g = 1,2,\ldots,63,$$

where x_{ig}, $i = 1,2,3$ are the self-evaluation scores on each rubric, and y_{ig}, $i = 1,2,3$ are the instructor scores. We then calculated the correlation coefficient between this measure of 'self-reflection' and the grade for the class and found correlation of $\rho_{gm} = -0.70$, that is, a significant negative correlation. This supports the hypothesis that students with better metacognition (i.e., ψ_g score close to zero) tend to have higher grades. This, of course, is a very preliminary analysis from an uncontrolled pilot study, but it does support the importance of metacognition. Further analysis of the existing data as well as further experimental studies are currently underway.

4. Student Experiences

Two weeks after the projects were submitted, we surveyed the students to learn how much time they had spent on the project, how they felt about working in groups, and how they perceived the project in relation to the course content. The online survey received 138 responses. Fifty-eight percent of respondents reported that their group as a whole had spent between 6 and 12 hours on the project, and 22% of the students said their group spent more than 12 hours on it. For 64% of the respondents, at least half of this time was spent directly using the system. Nearly half of the students said that as individuals they had spent between 4 and 8 hours on the project; 21% stated that they spent more than 8 hours on it. The students were overwhelmingly positive about working in groups, with 62% selecting an optimal group size of 3 students.

When asked if the course content had sufficiently prepared them to complete the case study, 80% of students responded positively. Those who cited deficiencies in preparation mentioned the material on project risk and uncertainty, which had not been started when they began the project, and some manufacturing knowledge such as scrap rates. Students also said they were confused by the extraneous actions, lacked problem-solving strategies, or wanted a more detailed problem description. As to whether the project helped them to learn the material, 25% answered yes, and an additional 53% said that it had mainly helped them to integrate the course material and see how to apply it in a real situation. Another question was whether they had used knowledge gained in other courses. A minority of the students mentioned using material from cost and managerial accounting courses; IE courses in manufacturing systems engineering and optimization; statistics; economics; marketing; and computing/knowledge of Excel. A few of the comments made be students on this evaluation are included below:

> "This was the best part of the course. The more hands on, the easier it is to understand. It helps to see why we do the calculations, and what a benefit it is to forecast such things."

> "It helped me visualize a real-life application of the material covered in this course. It also forced me to develop my own problem-solving steps that I can apply to solving problems presented in the course material."

> "It was a very good learning experience. It seemed like something that would be assigned on an actual job. It should be assigned every semester for an actual assignment."

> "The grids [rubrics] helped determine what was expected of the project."

> "It was a good learning tool, really applicable to class studies."

5. An Integrated Learning Environment

In this section we broaden our focus to discuss designs for extending the pilot study, involving the single module developed for an engineering economy course, to an integrated learning environment consisting of a network of such modules.

As was pointed out in the introduction, although it is widely accepted that information technology may be used as a vehicle to improve engineering education, doing so will require a careful consideration of both technical content and of learning objectives so that the technology environment promotes learning that we value and effectively delivers the technical content. To increase its usefulness it should also be used to address challenges in the existing curriculum that may be difficult to solve without the enabling technology. Some of these challenges were identified in the introduction, and highlighted by the module described above.

Thus, in rethinking the entire curriculum, we are in the process of designing a new active learning environment where for each course students complete one or more modules that relate to the course content. These modules will be designed to accomplish numerous goals identified as being desirable:

- Each module will present a realistic engineering problem that students must solve using the tools acquired during the course. This helps the students to not only make a connection between the course material and a real-world problem, but also develop their ability to apply discipline-specific knowledge to solve engineering problems and monitor their problem solving strategies.
- The modules will be interconnected so that the relationships between previously isolated parts of the curriculum are made apparent. Over a set of several courses students will therefore develop a better appreciation of the connections among courses.
- The modules will focus on helping students develop both their cognitive ability to structure schemas in industrial engineering knowledge domains and develop their metacognitive ability by reflecting on their solutions and justifying each action that is made.

As in the engineering economy module, for each module students must independently define goals, formulate problems, and develop solution strategies while mastering the course material. This environment is thus a fundamental shift from the existing emphasis on the traditional lecture format to active learning[12,13]. This is also an ideal tool to encourage cooperation and communication with other students through collaborative learning[19].

One of the means by which information technology (IT) can support learning is to present real-world problems as part of the curriculum and to create an active environment where students formulate and solve difficult problems using the tools learned in class[4]. Our new learning environment is heavily centered on such realistic problems developed in cooperation with industry partners.

As the development of additional modules in the new learning environment continues, one of the key focus areas will be the integration of the industrial engineering curriculum. The motivation behind this is that the traditional industrial engineering curriculum encompasses what may seem like loosely connected courses that address different elements of manufacturing and service enterprises. The engineering economy module is the first piece in a common IT-based environment that will be used to integrate these courses, and at the same time encourage the development of specific learning skills. Thus, modules will deliberately highlight connections between the content of multiple courses. This will be achieved by such mechanisms as solving two closely related problems using material from two different courses and using the output of a module from one class as an input to a different module. This type of integration would be difficult to achieve without the use of information technology. In the IT-based modules linkages will also be made via common interfaces and databases, which allows the students to focus on the content connections among the courses.

The fact that we are using IT to achieve this integration of the curriculum also enhances a student's ability to solve engineering problems. In the past, and continuing to some extent for traditional engineering disciplines, foundational knowledge in mathematics and engineering sciences helped to integrate curricula as the concepts and tools introduced in the first two years were reinforced and expanded by their application in subsequent, discipline-specific courses. For industrial engineering, we see information technology increasingly taking over this integrative function. However, the typical curriculum has not been revised sufficiently to allow the IT we teach our freshmen to permeate the subsequent coursework. The key concept of this approach is a common learning environment based on new and emerging information technology tools and ideas that integrate isolated course content.

Another effective use of IT to enhance learning is increased capacity for providing students with timely feedback, and to encourage reflection and revision on the part of the students. Using formative assessment for feedback and to encourage learning from mistakes is an integral part of this environment but has not yet been implemented as part of the engineering economy prototype module. However, special effort has been made to incorporate student reflection into the environment via student self-evaluations and explanations of actions (see Section 3 above). This is again something that is difficult to achieve without the enabling technology.

6. Conclusions and Future Work

We have described the design of a new active learning environment that uses information technology to allow students to tackle realistic problems using state-of-the-art tools, and at the same time it promotes the engineering problem solving process and students' metacognition. Currently one module has been developed and a pilot study conducted in a classroom setting. As more modules are developed, this environment will serve to integrate required undergraduate classes in the curriculum by highlighting the connections between topics and providing a common learning environment.

Future work will develop at least one module for each required undergraduate course, but there is also considerable ongoing and future work on assessing the value of this environment. We are currently designing the second module for the manufacturing systems engineering course that will use the output of the existing engineering economy module to assist in the selection between several manufacturing processes for the same production scenario. One of the greatest potential benefits of using information technology for instruction is that it can make feedback easier to give by the instructor and revision easier for the students[4]. We are therefore considering how to effectively incorporate formative assessment into the current module and how to design more effective feedback mechanisms for students' reflection on their solution process. Other future research includes for example investigating more closely how to evaluate the benefits of encouraging metacognitive skills within a module.

Acknowledgements

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Biographies

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Sarah Ryan is an Associate Professor of Industrial Engineering at Iowa State University. She teaches courses in operations research as well as the engineering economic analysis course in which the module was initially tested. Her research focuses on stochastic models of manufacturing and service systems to support capacity expansion and allocation decisions.